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EFFECTIVENESS OF FERRITE CABLE FOR PYROTECHNIC TRAINING SIMULATOR APPLICATIONS

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August 1999



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13. ABSTRACT Electrically initiated pyrotechnic training simulators fielded in training operations are exposed to severe electromagnetic radiation environments; which with a growing reliance on the frequency spectrum, are expected to increase in severity. Unfortunately, beyond intended purpose, this electromagnetic radiation energy behaves as an <i>ignition stimuli</i> for electrically initiated pyrotechnic simulators using commercially produced bridge wire electric match igniters. In the configuration where the ignition cable and igniter element remain unprotected, the electromagnetic radiation energy may induce undesirable electrical currents in the pyrotechnic munition ignition system, which in turn, pass through and heat the bridge wire sufficiently to cause inadvertent igniter function and injury producing accidents. The effectiveness of ferrite cable used in place of conventional cable to combat hostile electromagnetic radiation environments was evaluated by testing retrofitted simulators in accordance with MIL-STD-464, "Department of Defense Interface Standard, Electromagnetic Environmental Effects Requirements for Systems." Results have been plotted and analyzed as a function of no-fire field intensity versus frequency for ferrite and conventional non-ferrite cable configuration for comparative purposes. It has been demonstrated that the application of ferrite cable in place of conventional cable for pyrotechnic simulator ignition systems has proven an effective means in reducing vulnerability to electromagnetic radiation stimuli.				
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INTRODUCTION

Electrically initiated pyrotechnic training simulators (munitions), fielded at training centers employing combined arms exercises and joint operations, are exposed to severe electromagnetic radiation environments; which with a growing reliance on the frequency spectrum, are expected to increase in severity. The development, fielding, and maturation of sophisticated electronic weaponry systems and communications equipment arising from the "digitization" of the battlefield will certainly add or couple electromagnetic fields generating even higher field strengths. Unfortunately, beyond its intended purpose, this electromagnetic radiation energy behaves as an *ignition stimuli* for electrically initiated pyrotechnic munitions using commercially produced bridge wire electric match igniters. In the configuration where the ignition cable and igniter element remain unprotected, the electromagnetic radiation energy may induce undesirable electrical currents in the pyrotechnic munition ignition system, which in turn, pass through and heat the bridge wire sufficiently to cause inadvertent igniter function and injury producing accidents. For the purpose of this study, the electrical ignition cable is identified as a victim receptor to hostile electromagnetic radiation requiring protection.

The objectives of this study were to achieve a greater understanding of ferrite cable with regard to ferrite materials, physical construction, performance, and measured effectiveness. Such an understanding is intended to benefit pyrotechnic munition design and production. Additionally, it will serve as a basis for the qualification of alternate ferrite cable products.

The application of ferrite cable in place of conventional cable for pyrotechnic munition ignition systems has been studied in reducing this vulnerability to electromagnetic radiation stimuli. Specifically, pyrotechnic munitions ignition systems relying on 20 to 22 AWG, polyethylene or polyvinylchloride (PVC) insulated, solid copper conductor, attached pair cable have realized significant reductions in electromagnetic radiation vulnerability when this conventional cable is replaced with ferrite jacketed cable.

Evaluation of vulnerability reduction effectiveness was based on laboratory testing conducted in accordance with MIL-STD-464, "Hazards of Electromagnetic Radiation to Ordnance (HERO)," as a benchmark for potential hostile training battlefield environments.

Other techniques to mitigate electromagnetic radiation vulnerabilities for pyrotechnic munitions such as the usage of shielded cable, twisted pairs, radio frequency (RF) filters, semi-conductor bridge igniters, laser ignition techniques, or ferrite devices other than ferrite cable, were not within the scope of this study.

FERRITE MATERIALS AND PHYSICAL CONSTRUCTION

Ferrite cable products offered by industry in the range of 20 to 28 AWG or equivalent, are typically centered on stranded, tin plated, copper conductors that serve as the transmission line carrying intended electrical currents. These conductors are axially encapsulated by a loosely bound ferrite material annularly located between the conductors and an outer insulating jacket. Ferrite materials adopted by the cable industry were predominantly found to be blended mixtures of hard, ceramic, inert materials; their principal ingredients identified as ferrous oxide and various oxide materials to include manganese, zinc, cobalt, and/or nickel oxide. Evidently, a shortfall of ferrite materials used in cabling is their lack of structural properties; having the consistency of a loosely packed fine powder. Ferrite materials and components are manufactured in various shapes and

forms; for example, they can be obtained in the forms of fine powder, beads, rod, and tile. As applied to ferrite cable, the ferrite powder or beads are commonly blended with an elastomer binder material by means of proprietary mixing and extrusion techniques such that a ferrite/elastomer mixture resides between the inner conductors and outer insulation jacket. Elastomers were identified as preferred binder materials since they promote high degrees of flexibility to the cable. Bordering the ferrite/elastomer mixture, the outer jacket has several purposes in that it: 1) physically contains the ferrite/ elastomer mixture, 2) insulates the conductors, and 3) protects the ferrite and conductor from hostile environments, e.g. abrasion, high temperature, and chemical attack.

PERFORMANCE OF FERRITE CABLE

The adoption of proven design measures on cables, in conjunction with the use of an extruded compound filled with lossy ferrite materials, provide a novel approach in protecting the victim receptor and mitigating electromagnetic environment effects problems experienced with conventional cable products in pyrotechnic munition design.

These ferrite based cables work mainly through the absorption of incident electromagnetic energy by the ferrite/elastomer mixture and conversion of such energy into heat which is rapidly dissipated; thereby, offering significantly improved performance compared to cables of standard construction.

The ferrite materials have a unique property in that they reduce the permeation of electromagnetic radiation whether that be a transmission line emission, as in the case of electromagnetic interference; or a transmission line induction, as the case of induced currents caused by electromagnetic radiation energies. The ferrite material effectively converts incident electromagnetic radiation energy into heat.

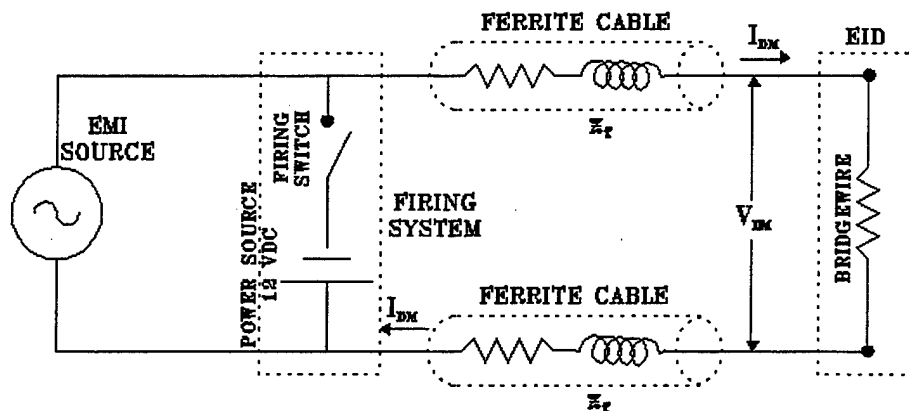


Figure 1
Equivalent circuit with ferrite cable in the electrical initiated device (EID)

Key to the study of ferrite materials is their impedance properties. Impedance (Z) is defined as a resistance R in series with a reactance X. Formula representation for impedance is: $Z = R \pm jX$. R is the resistance and X is the reactance component of the impedance. The inductive reactance can be written as $(+j\omega L)$; and the capacitive reactance can be written as $(-j/(\omega C))$.

Where $\omega = 2\pi f$. f is the frequency

Where $X = X_L - X_C$. In ohms

X_L is defined as inductive reactance; the opposition of inductance to alternating current

X_C is defined as capacitive reactance; the opposition of capacitance to alternating current

In a constant-potential circuit that contains inductive reactance and also capacitive reactance in series, by adjusting the frequency, it is possible to obtain the resonance frequency at $f = 1/(2\pi LC)^{1/2}$ which makes $X_L = X_C$ and the impedance will be $Z = R$. These conditions will give the highest current for the circuit. It is the worst case for electromagnetic radiation energy. Due to high frequency, the impedance Z is dominated by the inductive reactance.

Studies have found that ferrite material behaves as an inductor. Based on this similarity, ferrite impedance can be written as $Z = R + j\omega L$ in a simple circuit for analysis. From the above impedance equation, $Z = R + j\omega L$, one can see that the ferrite impedance is frequency dependent. This is a result of the $2\pi f$ component. In other words, at low frequency, the impedance is low, and the ferrite cable will pass the signals with minimum loss. At high frequency, the impedance of the ferrite cable is high; the signals will be reduced significantly and dissipated in the form of heat. Thereby, the ferrite cable offers a frequency dependent resistance.

As indicated, the ferrite cable can eliminate the high frequency signals by dissipating them as heat. At the same time, the ferrite cable allows the low frequency signals to propagate with minimum attenuation. The other major advantage of ferrite cable is that it does not require grounding. With this uniqueness, ferrite acts as a filter for the cable, that absorbs the electromagnetic energy and dissipates it in form of heat. For conventionally shielded cables, true grounding is required to mitigate currents induced by electromagnetic energy. When applied to electrically initiated pyrotechnic munitions, it is very difficult for end item users to obtain sufficient grounding when the munition is being removed from its transportation packaging and loaded into firing devices. Further, should grounding techniques be attempted, improper installation of ground lines can actually increase the noise and compound the adverse effects of high electromagnetic radiation environments. Ferrite cable products serve a highly effective solution for this challenge. Given the unique property to absorb electromagnetic energy and convert such to heat without grounding measures, ferrite cable has excellent properties and design characteristics for electrically initiated pyrotechnic munitions/system applications.

EFFECTIVENESS EVALUATION

The effectiveness of ferrite cable in combating hostile electromagnetic radiation environments was evaluated by retrofitting a simulator with ferrite cable and testing such in accordance with MIL-STD-464, "Department of Defense Interface Standard, Electromagnetic Environmental Effects Requirements for Systems". Commonalties in ignition system design affecting various pyrotechnic training simulators were considered in selecting a representative configuration. An artillery flash

simulator was selected as a test platform for evaluation and an inert simulator was retrofitted with ferrite cable, instrumented, and tested per MIL-STD-464, para. 5.8.3 "Hazards of Electromagnetic Radiation to Ordnance (HERO)." It should be recognized that this test was conducted at the item level, on an unpacked simulator, and does not represent the subsystem level (firing device) or system level (operational training system).

TEST INSTRUMENTATION AND PROCEDURE

Various instrumentation techniques, such as thermocouple and fiber optic temperature sensors, RF voltage or current detectors, temperature sensitive waxes, or substitution of more sensitive elements, may be employed to measure the effects of electromagnetic radiation environments on an electrically initiated device. Instrumentation selected for the test must not alter the system's inherent (non-instrumented) response characteristics and must maintain electromagnetic equivalence. The instrument's sensitivity and response time must be sufficient to capture maximum RF-induced response of the device or firing circuits at specified electromagnetic environments.

Recognizing that the artillery flash simulator employs a bridge-wire electric match initiator, instrumentation was fabricated to evaluate the influence of electromagnetic radiation at this critical point. In this, the bridge-wire was replaced with a sensor fabricated to measure the induced currents generated by electromagnetic radiation energy. The sensor was based on a replacement bridge-wire coated with a phosphorous material coupled to a fiber optic line and fiber optic receiver. In general, as the electromagnetic field induces a current in the pyrotechnic simulator's ignition system, the replacement bridge wire heats up the phosphorous material which emits optic energy that is measured at the fiber optic receiver. Once the electromagnetic radiation energy is removed, the induced current returns to zero and the fluorescent decay time of the phosphorous is measured. This decay time is then correlated with the phosphor temperature field intensity by comparing the decay time with data in a digit look up table via a computer software program.

The following formula is used to calculate the NFFI for the MIL-STD-464 HERO criteria.

$$NFFI = (F_i \cdot S_f)(I_n / I_b)$$

where

NFFI = the no-fire field intensity in volts/meter.

F_i = Field intensity measured volts/meters

S_f = Safety factor (.15 for the Army)

I_n = No Fire Current (250 ma)

I_b = Current measured by the fiber optic sensor from frequency source.

TEST RESULTS

The MIL-STD-464 HERO test results have been plotted as a function of NFFI (V/m) versus frequency (MHz). Graphical presentation of the artillery flash simulator fitted with a) solid copper/polyethylene jacketed (standard) cable, b) two ferrite cable products are provided in the data charts in the appendix. The MIL-STD-464 threshold (i.e. requirement) and corresponding artillery flash simulator response have been plotted and identified in the data charts (app). One can see by the

definition of NFFI, that NFFI is inversely proportional to the current induced at the initiator's bridge wire. Thereby, as the induced current at the bridge or "pick-up" increases, the NFFI response decreases. NFFI responses falling below the MIL-STD-464 requirement are considered HERO failure regions. Results demonstrate the artillery flash simulator fitted with solid copper/ polyethylene jacketed (standard) cable fails to meet the MIL-STD-464 HERO requirements with notable failures between approximately 400 to 450 MHz, 800 to 900 MHz, and 1 GHz to 10.5 GHz. Considering the two ferrite cable products evaluated, results demonstrate a product that fully meets the MIL-STD-464 HERO requirement and a second product that portrayed one failure between approximately 400 to 700 MHz.

CONCLUSIONS

Ferrite materials adopted by the cable industry were predominantly found to be blended mixtures of hard, ceramic, inert materials; their principal ingredients identified as ferrous oxide and various oxide materials to include manganese, zinc, cobalt, and/or nickel oxide. Evidently, a shortfall of ferrite materials used in cabling is their lack of structural properties; having the consistency of a loosely packed fine powder. As applied to ferrite cable, the ferrite powder is commonly blended with an elastomer binder material by means of proprietary mixing and extrusion techniques such that a ferrite/elastomer mixture resides between the inner conductors and outer insulation jacket.

Key to the study of ferrite materials are their impedance properties. Ferrite cable behaves as an inductor or filter in that, at low frequency the impedance is low and the ferrite cable passes electrical signals with minimum loss. In contrast, at high frequencies, the impedance of the ferrite becomes high and the electrical signals are reduced significantly and dissipated in the form of heat. The other major advantage of ferrite cable is that it does not require grounding; whereby in the case of conventionally shielded cables, true grounding is required to mitigate currents induced by electromagnetic energy.

The effectiveness of ferrite cable in combating hostile electromagnetic radiation environments was evaluated by retrofitting a simulator with ferrite cable and testing such in accordance with MIL-STD-464, "Department of Defense Interface Standard, Electromagnetic Environmental Effects Requirements for Systems." Results have been plotted as a function of the no-fire field intensity versus frequency for artillery flash simulator items retrofitted with ferrite cable; likewise, for the standard non-ferrite cable configuration for comparative purposes.

Results demonstrate the artillery flash simulator fitted with solid copper/ polyethylene jacketed (standard) cable fails to meet the MIL-STD-464 HERO requirements with notable failures between approximately 400 to 450 MHz, 800 to 900 MHz, and 1 GHz to 10.5 GHz. Considering the two ferrite cable products evaluated, results demonstrate a product that fully meets the MIL-STD-464 HERO requirement and a second product that portrayed one failure between approximately 400 to 700 MHz.

APPENDIX A
RESULTS OF MIL-STD-464 HERO TEST

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ARTILLERY FLASH SIMULATOR FITTED WITH SOLID COPPER/POLYETHYLENE JACKETED (STANDARD) CABLE

CONFIGURATION:

VERTICALLY FACING ANTENNA

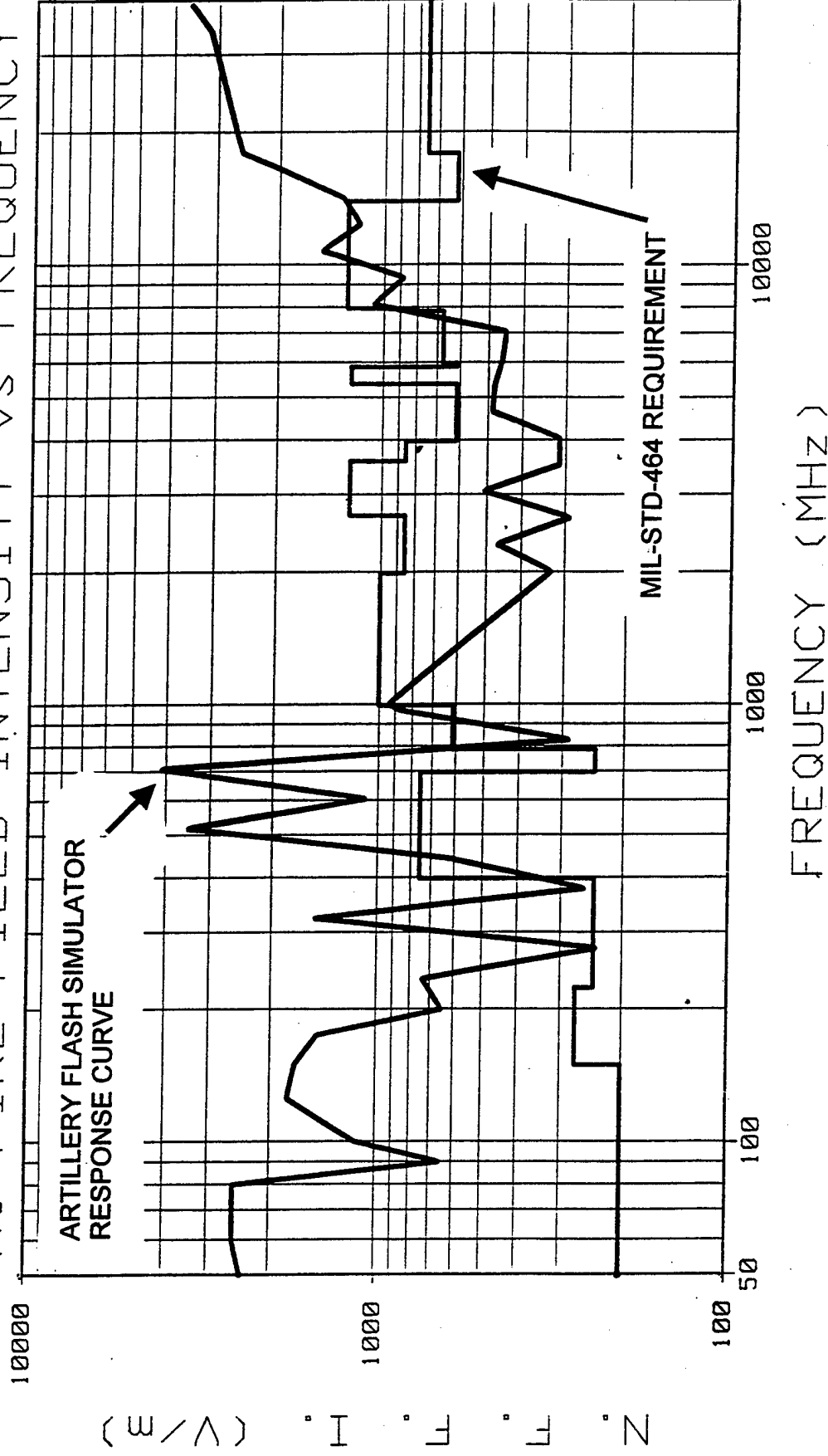
CHANNEL:

TEST ITEM ORIENTATION WITH RESPECT TO ANTENNA: 0 DEGREES

APPLICABLE SPECIFICATIONS: MIL-STD-464

SAFETY FACTOR: 16.5 dB (.15)

NO FIRE FIELD INTENSITY VS FREQUENCY



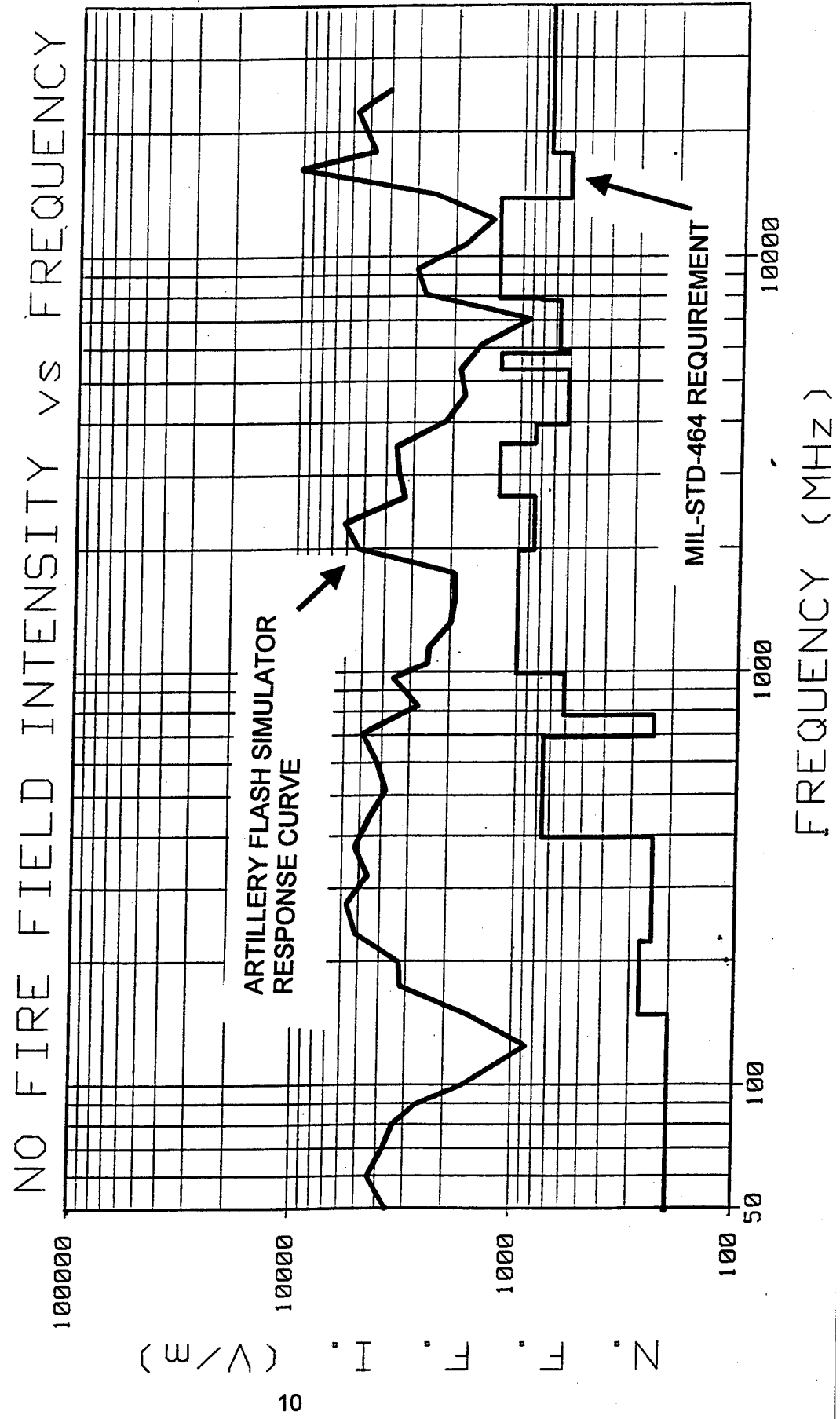
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ARTILLERY FLASH SIMULATOR FITTED WITH A FERRITE JACKETED CABLE

CONFIGURATION:
CHANNEL.

APPLICABLE SPECIFICATIONS: MIL-STD-464

SAFETY FACTOR: 16.5 dB (.15)



ARTILLERY FLASH SIMULATOR FITTED WITH A FERRITE JACKETED CABLE

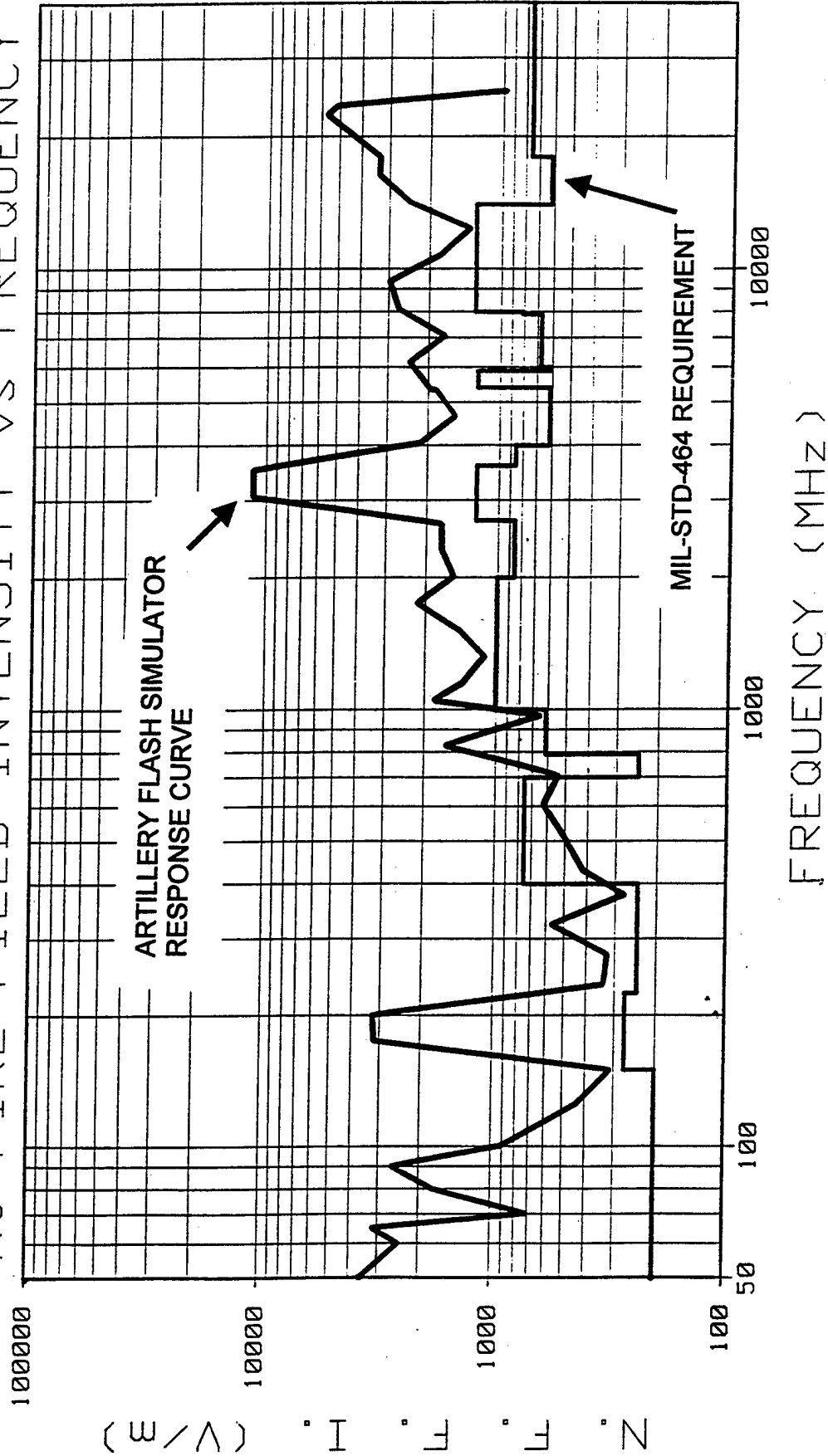
CONFIGURATION.

CHANNEL:

APPLICABLE SPECIFICATIONS: MIL-STD-464

SAFETY FACTOR: 16.5 dB (.15)

NO FIRE FIELD INTENSITY VS FREQUENCY



**NOT MEASUREMENT
SENSITIVE**

**MIL-STD-464
18 March 1997**

**SUPERSEDING
(See section 6.4)**

DEPARTMENT OF DEFENSE INTERFACE STANDARD

ELECTROMAGNETIC ENVIRONMENTAL EFFECTS REQUIREMENTS FOR SYSTEMS



AMSC A7252

AREA EMCS

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